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Western white pine (Pinus monticola Dougl.) is affected with a potentially serious disease known as pole blight.[1/] Although the cause of the disease is not definitely known after nearly 10 years of intensive research by several agencies, pole blight appears to be a disorder or complex of disorders associated with soil and soil moisture deficiencies. In addition, high rootlet mortality and low rootlet density in the root systems of white pine stands affected with pole blight are significantly correlated with a low available moisture storage capacity in the upper 3 feet of soil supporting these stands (5).[2/] As white pine is the only species in the western white pine type affected with pole blight, one avenue of study is to develop a means for comparing the relative ability of white pine to compete with associated tree species for available soil moisture. This report summarizes the results of such a study, using root structure, habit, and abundance as the means of comparison.

A number of workers, Ehrlich and Baker,[3/] Gill and associates,[4/] McMinn (7), and Leaphart and Copeland (5) have demonstrated both severe root and rootlet deterioration of white pine in pole blight-diseased stands. Certain evidence suggests this condition precedes crown symptom development (5). Root deterioration is worse when the crown symptoms are more severe.

Although studies of root systems of other coniferous species in the western white pine type are limited, root characteristics of white pine are better known. In healthy stands, ranging from 20 to 160 years old and occurring on various sites, the extent of the white pine root system and the density of its rootlets are functions of stand age, site index, and white pine basal area per acre (5). Rootlet mortality in this species averaged 4.4 percent for all stands combined but was not correlated with any of the above stand factors. The range was from 1.5 to 9.6 percent with both extremes occurring in the 20- to 40-year age class, the youngest age class sampled. Approximately 65 percent of the total root system, exclusive of the central vertical system, occurs in the uppermost 1 foot of the top 3 feet of soil supporting healthy 60- to 80-year-old white pine.

McMinn (7) has shown that in pole stands white pine forms a widespread root system extending more than 26 feet laterally from the root collar and with verticals descending off the lateral system as well as in a concentration beneath the root collar. Douglas-fir and western hemlock, in comparison to white pine, have a more profuse arrangement of fine roots and rootlets.

The form of the white pine vertical system and the depth to which it penetrates depend on external conditions. Unpublished data from studies by the author show that vertical roots larger than 6.0 mm. in diameter originating from the lateral system are seldom encountered below 2 feet in 60- to 80-year-old white pine stands growing on sites where rock or hardpan materials reach high densities in the 1- to 2-foot levels. Investigations by Gill and his associates[5/] and McMinn[6/] of trees of the same age class substantiate these findings.

1/ For detailed accounts of symptoms of this disease and the damage it causes, the reader should refer to other publications (1, 2, 3, 6).

2/ Numbers in parenthesis refer to LITERATURE CITED, p. 10.

3/ Ehrlich, John, and Loren K. Baker. Preliminary study of dying of young white pine on Coeur d'Alene and Kaniksu Forests. University of Idaho, School of Forestry. Typewritten report, 50 pp. 1942.

4/ Gill, Lake S., Stewart R. Andrews, and R. E. Millenbaugh. Pole blight investigations by forest pathology. Bureau of Plant Industry, Soils, and Agricultural Engineering, Division of Forest Pathology. Typewritten report, 22 pp. May 9, 1948.

5/ See footnote 4.

6/ McMinn, R. G. Studies on the root systems of healthy and pole blight affected white pine (Pinus monticola Dougl.). Canada Dept. Agr., Forest Biology Laboratory, Victoria, B. C., Interim Report. 31 pp. plus 4 plates, mimeographed. 1955.

Haig (4) showed drought resistance of grand fir (Abies grandis) (Dougl.) Lindl.), Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco), western larch (Larix occidentalis Nutt.), western white pine, western redcedar (Thuja plicata Donn.), and western hemlock (Tsuga heterophylla (Raf.) Sarg.) to be closely linked to root penetration in the seedling stage. Depth of penetration was in the order presented, with grand fir root systems penetrating the deepest.

METHODS OF STUDY

Study Area

The data used in subsequent analyses were collected on the Priest River Experimental Forest in northern Idaho from a 1-acre area in a white pine stand where pole blight was first observed in 1941. Ten trees, making up approximately 17 percent of the white pine basal area on the study plot, were affected in 1956. All data were obtained in 1956 during July, August, and September.

Eight species were represented on the study area. Their number and basal area are shown in table 1. McMinn (7) has found that the dominant trees of white pine have a greater length of fine roots per unit length of structural root than intermediate or suppressed trees. The percentage of trees in the upper or dominant story of the stand is, therefore, given by species to show to what class of trees the root data are probably related, even though correlations have not been established for the associated species.

Table 1.--Species stand table of the root study area showing number of stems and basal area per acre and the percentage of trees in the dominant and codominant crown classes

Species	Stems by d.b.h. class		Basal area per acre[1/]	Trees in the upperstory
	0.6" to 5.9"	6.0+"		
	Number		Sq. ft.	Percent
Western larch	36	215	91.86	86
Western white pine	107	83	55.04	33
Western redcedar	568	63	44.17	0
Douglas-fir	37	37	16.01	24
Western hemlock	19	14	5.22	3
Lodgepole pine	0	5	4.39	100
Grand fir	0	3	1.36	100
Engelmann spruce[2/]	0	2	1.33	100

1/ Includes all stems 0.6 inch in diameter and larger.
2/ Picea engelmannii Pasby.

The stand was on relatively flat ground with a hardpan of lacustrine deposit occurring at an average depth of 17 inches.[7/] Available moisture at field capacity for the soil to hardpan at 17 inches averaged 3.18 inches; for the first foot of soil, 1.85; the second, 3.32; the third, 3.33; and the fourth, 3.18. The site index for white pine on the area is 60, considered fair to good for this species.

The average annual rainfall for the area since 1913 has been 30.40 inches. Precipitation for the summer period, June 1 to September 30, has averaged 5.92 inches since 1912. Stage (8) has pointed out that summer precipitation and stored soil moisture are inadequate to meet the potential evapotranspiration on the study area. The moisture deficit, which may be defined as moisture that could have been used had it been available, was 3.7 inches for the period from about mid-June to mid-October.

7/ All soils data were furnished by Dr. Otis L. Copeland, Jr., soil scientist, who has worked with the author on all root and soil condition studies on pole blight investigations. Physical soil characteristics on the study area were determined to a depth of 4 feet.

Field Procedures

Root systems of the trees were studied in a stand rather than on an individual tree basis. Roots were obtained by a sampler that removed a cylindrical soil core 6 inches in diameter by 12 inches deep. These roots provided the basic data for subsequent study and analysis.

Fifty soil cores were collected from the upper 1 foot of soil. The sample points, approximately 30 feet apart, were systematically arranged within the acre. Additional core samples from this soil horizon were taken around selected trees of Engelmann spruce, grand fir, lodgepole pine, western hemlock, and western larch within the study area to obtain an adequate number of samples to represent these species. These samples were obtained at 5, 10, and 15 feet from the base of the selected tree on eight lines running N., E., S., W., NE., SE., SW., and NW. from the trees.

Each core sample was washed individually in a wire screen container. Soil was carefully removed from about the root sections to prevent loss of root tips and fine root material. Only live root sections 2.0 mm. and larger in diameter with and without attached finer roots were retained for analysis from the top 1 foot of soil, but roots of all sizes were retained from depths between 1 and 4 feet. In all cases the larger diameter root to which a smaller root was attached is hereafter considered the parent lateral root.

The data obtained for each species and each core sample were recorded on a separate summary sheet. All root sections were grouped by species and sample and measured by diameter class.[8/] Attached roots were recorded in their appropriate subgroup diameter class under the diameter class of the parent root. Both dead and live rootlets (those roots less than 1.0 mm. in diameter) were tallied by the diameter class of the root to which they were attached. A live rootlet was one having at least one live root tip or that was alive at its distal end if the tip had been broken off by sampling or in the washing process. For unbranched rootlets or those having no branches longer than 4.9 mm., the rootlet was tallied once for both rootlet and root tip and the live length was measured. For branched rootlets with branches 5.0 mm. in length or longer, the total length of rootlets plus qualifying branches was recorded. The rootlet was tallied once and the total number of live and dead root tips on all qualifying branches was determined. A binocular microscope was used to decide whether a root tip was alive or dead.

Pits were dug at 10 points, randomly selected from the fifty 0- to 1-foot level sample points. Using the same sampling procedure, two samples were collected from each of the 1- to 2-, 2- to 3-, and 3- to 4-foot levels in all pits. The data from the two samples at each level were averaged for each pit. These averaged data were used with those from the 0- to 1-foot samples in evaluating root penetration and distribution of each species.

RESULTS

The data from the individual tree samples and the 50 systematic samples at the 0- to 1-foot level were combined and subjected to covariance analysis. In comparing other data with those in this paper, it must be remembered that some of the western white pine stems in the study area were diseased. This influenced the abundance of roots of white pine trees. In a normal healthy stand this species has a more profuse root system (5). It is unknown if the root systems of the other species increase in healthy areas in the same proportion. Observations by the author in the course of other root studies throughout the white pine type suggest, however, a development in these species at least equal to or greater than that on the study area.

Table 2 shows the ratios of rootlet length to length of parent lateral root, arranged in their order or magnitude, by selected diameter classes and species. The length of rootlet per unit of structural root is quite low in white pine in comparison to the other species. Although a significant difference occurs between white pine and the other subclimax species (larch, Douglas-fir, and lodgepole pine), the most striking difference is between the fine root densities of the climax and the

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8/ Roots of many coniferous and herbaceous species were encountered in the samples. However, identification of the roots of conifers reported on in this study was relatively simple for all size classes above 2.0 mm. in diameter. Roots smaller than 2.0 mm. in diameter were not as easily identified, and some of these were grouped in an "unknown" category despite the use of a key especially devised for this project. This key will be published in coauthorship with Dr. R. L. Gilbertson and Mr. Frederic D. Johnson, College of Forestry, University of Idaho, Moscow, Idaho.

subclimax groups. The climax group which includes cedar, hemlock, grand fir, and spruce[9] has approximately two to four times the rootlet length per equivalent length of parent lateral root.

Table 2.--Ratios[1] of rootlet length to length of parent lateral root of tree species in a white pine stand affected with pole blight

Species	Sample size[2]	Diameter class of parent lateral root	
		1.0 - 10.0 mm.	1.0 - 25.1> mm.
Western white pine	52	0.43	0.39
Western larch	99	.73	.70
Douglas-fir	49	1.00	.86
Lodgepole pine	33	1.02	.92
Western hemlock	40	2.13	2.09
Grand fir	31	2.19	2.08
Western redcedar	48	2.37	2.27
Engelmann spruce	29	2.44	2.22

1/ Each ratio was obtained by dividing the adjusted length of rootlet of each species by the mean length of parent lateral root of all species for each diameter class as computed by covariance analysis.

2/ Number of soil samples containing roots of the species.

The climax species had a fairly good absorbing system throughout most of their structural system, whereas the rootlets were scarce or absent on the larger diameter roots of the subclimax species. The ratios of length of rootlet to the length of parent lateral root by species is given below for the 10.0 to 25.1> mm. diameter class.

Species	Ratio of length of rootlet to length of parent root
Douglas-fir	0.000
Lodgepole pine	.005
Western white pine	.010
Western larch	.090
Grand fir	.260
Engelmann spruce	.610
Western redcedar	.960
Western hemlock	1.540

Only larch, cedar, hemlock, spruce, and grand fir had fine roots attached to roots larger than 15.1 mm. in diameter. Rootlets were present on parent roots larger than 25.1 mm. on larch, hemlock, and spruce. Even for roots in the 5.1 to 10 mm. diameter class, the climax species had approximately 10 times the length of fine root as the subclimax species. Although the effect is not so great in the climax species, both the figures above and those in table 2 show that the length of structural root in the larger diameter classes generally reduces the abundance of fine roots for the total length of the lateral system.

The adjusted number of root tips of each species per mean length of parent lateral root of all species was also computed by covariance analysis. The number of root tips per centimeter of parent lateral root in the 1.0 to 15.0 mm. diameter class was subsequently determined and is shown as follows:

9/ Engelmann spruce is not climax at the test site although at higher elevations within the white pine type it becomes one of the climax species in association with alpine fir (Abies lasiocarpa (Hook.) Nutt.) and mountain hemlock (Tsuga mertensiana (Bong.) Carr.). For this reason it is included in this group.

Species	Adjusted numbers
Western white pine	0.4
Douglas-fir	.6
Western larch	.7
lodgepole pine	.7
Western redcedar	1.1
Western hemlock	1.5
Grand fir	1.5
Engelmann spruce	1.5

White pine, as in other comparisons, ranks well below the other species. Whereas white pine has nearly half the root tip density of its subclimax competitors, it has less than one-fourth as many root tips as the climax species, cedar excepted. The tabulation shows that its competitors branch much more profusely, at least in stands affected by pole blight. A similar analysis was made for rootlets attached to roots 1.0 to 25.1>mm. in diameter. The adjusted number did not vary greatly from the figures shown above. This would indicate that although there is generally less rootlet length in the larger diameter class, the rootlets that do occur branch just as profusely as when attached to smaller diameter roots.

Less difference was found between species in the number of root tips per rootlet than in all other root characteristics. Significant differences did occur, however, between the three climax species, cedar, hemlock, and spruce, and the other five species. These five were nearly equal in the number of root tips per rootlet as the following tabulation shows.

Species	Root tips per rootlet
Western white pine	2.1
Grand fir	2.3
Western larch	2.5
Douglas-fir	2.5
Lodgepole pine	2.8
Western redcedar	3.2
Western hemlock	3.5
Engelmann spruce	3.5

These figures and those above show that the subclimax species, white pine particularly, not only have fewer root tips per rootlet than the climax species, but also have fewer rootlets on which the absorbing system can develop.

Average rootlet and root tip mortality of each tree species is given in figure 1. Both are less in white pine than in all other species though not greatly less than in Engelmann spruce. Lodgepole pine, Douglas-fir, grand fir, and cedar, in descending order, show considerably higher mortality, while hemlock and larch rank intermediate between both groups. Previous studies by the author (5) have shown that rootlet density is approximately two times higher in white pine root systems in healthy stands on good sites than on sites similar to the study area. It is puzzling to find that white pine on this area has a low rootlet and root tip mortality yet a low density of fine roots compared to the other species with high mortality rates and still a high density fine root system. Either the ability of white pine to regenerate its root system, even with a low mortality, falls well below that of the other species, or a period or periods of undetermined duration previous to this study occurred during which rootlet mortality in white pine was considerably higher and resulted in the present low density of fine roots. Possibly both explanations apply. Some information is available to support only the latter hypothesis. High rootlet mortality in pole-sized white pine has occurred in recent years and has been correlated with low summer precipitation (5). These data, however, have not been checked experimentally.

White or fresh, and presumably newly formed, root tips were observed on roots of all species throughout the sampling period. This condition was observed most frequently in western redcedar, next in western white pine and grand fir, and less commonly in other species. Apparently neither the spring nor fall peak in root tip production, if such occurs in these species, was encountered in the sampling although a slight uptrend appeared in the latter part of September.

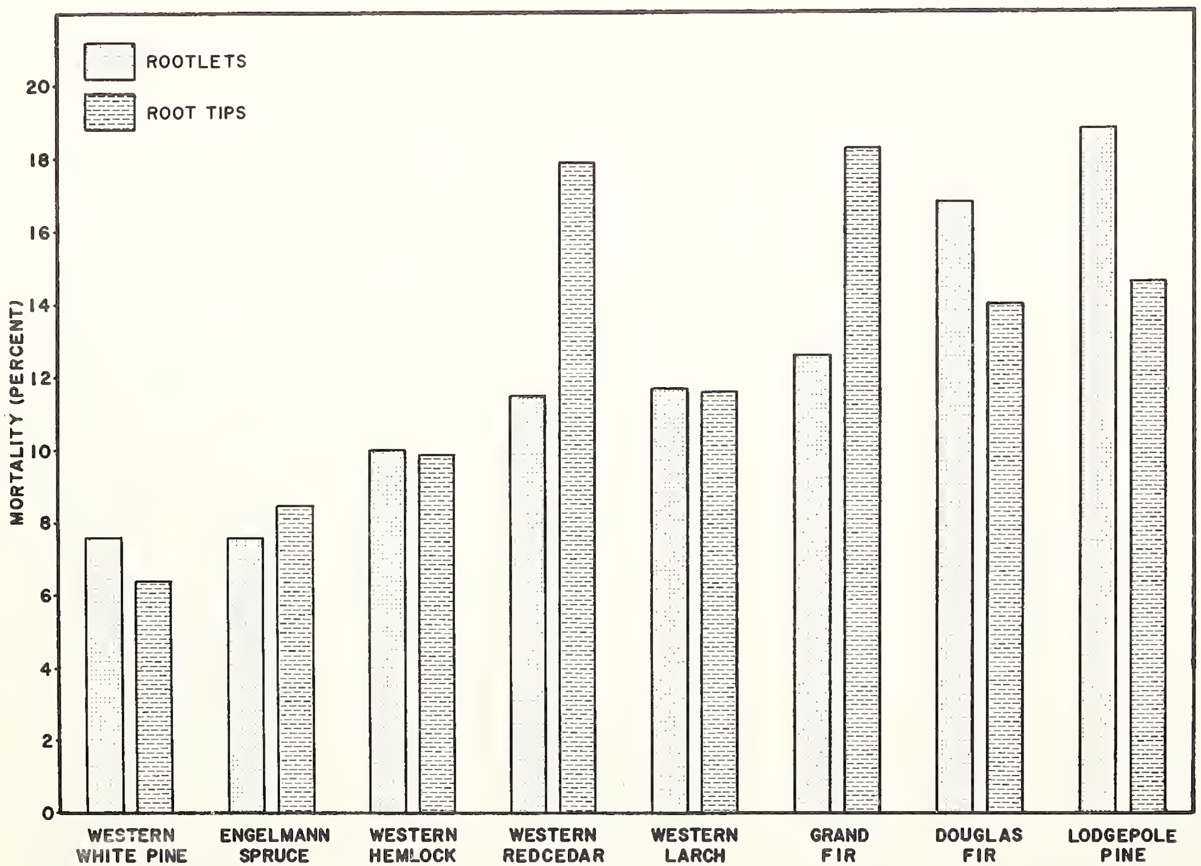

Figure 1.--Average rootlet and root tip mortality of tree species in a white pine stand affected with pole blight.

The lateral distribution and extent of the root system of each species could not be determined accurately by the sampling procedure employed. On the basis of the 50 samples evenly distributed about the plot, however, the total root length per square foot of basal area per species is illustrated in figure 2. Because of the limited number of samples, little reliance should be placed on the graphs except for those of white pine, larch, cedar, and to some extent Douglas-fir. White pine ranks next to three of the climax species in root abundance per square foot of basal area but certainly does not appear to be in the same competitive bracket.

White pine, on the basis of the samples taken to a depth of 4 feet, surpasses other species in depth of penetration and distribution of its lateral-vertical root system at greater depths. Table 3 shows the distribution of roots, rootlet length per unit length of parent root, and other root characteristics of each species by soil depths. Figures for hemlock, spruce, grand fir, and lodgepole pine are not included because of the very small number of roots obtained in the samples for these species.

Though hardpan material with a bulk density of 1.6 or greater retards root penetration, roots of all species except lodgepole pine, Douglas-fir, and hemlock were found in and below it. The smaller roots of all species were commonly encountered just above and in the upper portion of this hardpan horizon, particularly the shallower rooted ones such as Engelmann spruce and western redcedar. The root system of western larch, usually considered to be a deep-rooted species, penetrated the hardpan layers only to a limited extent but more effectively than all species except white pine.

Outstanding differences in vertical distribution in white pine are shown between the fine root condition above and below the 2-foot level. White pine is better equipped at the lower depths with fine roots on a unit root length basis than other species, but larch nearly equaled it in the 1- to 5-mm. class at the 3- to 4-foot depth. Why this difference occurs in white pine is not understood, but for its roots that do penetrate to areas below the hardpan layer, competition for moisture is not as severe since available moisture is almost twice that in the upper 1-foot level, and both root and rootlet density of all species is considerably less. Despite good conditions for the fine root growth, mycorrhizal development below the hardpan was almost nonexistent, but root hairs were found in abundance. Just the reverse conditions occurred above the hardpan.

Rootlet mortality was also considerably less for white pine at the lower soil depths than at the 1-foot level. Mortality in the other species was high compared to that in white pine. White pine structural root distribution by soil depths was quite similar to that observed in other areas (5). Approximately 40 percent of the absorbing surface was below the 2-foot level in the white pine system compared to 20 percent or less for the other species.

The total length of live conifer root sections less than 2.0 mm. in diameter that were not attached to larger roots was recorded for the three soil levels below 1 foot (table 3). Western redcedar showed a much higher total figure for the entire 1- to 4-foot horizon, but similar to white pine at both the 2- to 3- and 3- to 4-foot levels. Engelmann spruce, normally considered a shallow-rooted species, was represented in one sample of each level. Hemlock was quite abundant in one sample at the 1- to 2-foot level.

DISCUSSION

The climax species appear to be well adapted to compete for available moisture in the pole blight area under study. Their greater number of root tips and greater length of rootlets, if this length is at all effective in absorption, furnish potentially severe competition for available moisture to white pine and the other subclimax species. In this regard, western redcedar may be the most effective competitor. The greater portion of its rootlet length is sheathed in a white spongy material somewhat similar to ectotrophic mycorrhizae. This sheath eventually disintegrates leaving a slender rootlet with normal red-colored thin bark. Since the sheath is not suberized, a considerable length of rootlet presumably can function quite effectively in moisture absorption in contrast to all other species where suberization of the rootlets extends nearly to the root tips or mycorrhizal tips.

For each given unit of soil containing roots of all species, climax species roots of all diameters with their attached rootlets occupy the soil area much more completely than the subclimax group. Whereas moisture may be absorbed along the entire length of structural root of the former, the species in the latter group largely depend on the distal portions of their root systems for uptake of moisture. White pine must transport water for greater distances since it has a greater structural root length than the other species except possibly grand fir and spruce (fig. 2) which have absorbing structures along their entire root length. This possibly adds another disadvantage in moisture competition

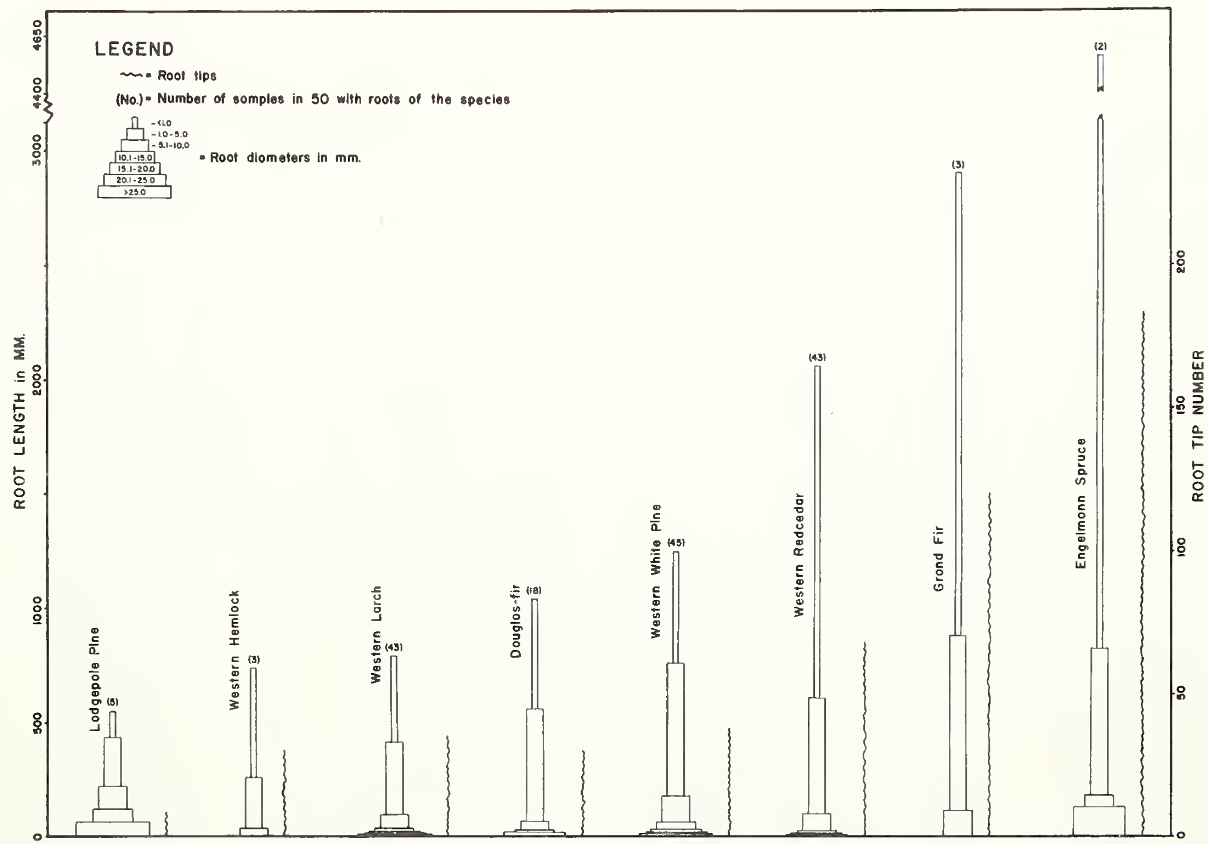

Figure 2.--Root length, by diameter class, and number of root tips per square foot of species basal area, in 50 soil samples per acre.

Table 3.--Distribution of roots by depth and diameter class for some tree species in a white pine stand affected with pole blight

Species	Soil depth	Ratio of total length of rootlet to total length of parent root by diameter classes (in mm.)			Mortality		Root length 1/	Distribution 2/ of root length by depth and diameter class (in mm.)						Sample basis 3/
		1.0-5.0	5.1-10.0	1.0-25.0	Root tips	Root-lets	< 2.0 mm.	<1.0	1.0-5.0	5.1-15.0	1.0-25.0	Root tips	Root-lets	
	Feet				Percent		Mm.	Percent						Number
Western white pine	0 to 1	0.76	0.31	0.62	7.0	6.0	-	59.6	70.9	84.1	67.5	54.0	44.2	10
	1 to 2	.61	.68	.62	2.5	2.3	6,584	9.4	13.8	4.6	10.6	10.4	11.3	10
	2 to 3	1.45	1.47	1.47	2.9	3.0	5,018	14.0	7.2	5.1	10.2	16.3	19.9	10
	3 to 4	1.65	1.85	1.71	3.0	2.4	2,861	17.0	8.1	6.2	11.7	19.3	24.6	9
Western larch	0 to 1	1.01	.20	.87	9.5	8.4	-	82.5	74.4	75.6	78.1	84.3	80.9	8
	1 to 2	.65	.01	.52	22.0	19.1	5,772	10.5	15.4	16.8	13.5	7.1	8.3	10
	2 to 3	.36	(4/)	.30	13.7	12.2	1,602	2.6	7.0	6.8	5.0	2.9	5.4	7
	3 to 4	1.31	(4/)	1.25	6.5	7.7	1,986	4.4	3.2	.8	3.4	5.7	5.4	5
Douglas-fir	0 to 1	.89	.58	.84	23.6	22.4	-	96.4	83.6	84.2	89.3	95.6	95.3	4
	1 to 2	.17	.20	.17	15.8	21.4	926	3.6	16.4	15.8	10.7	4.4	4.7	5
	2 to 3	-	(5/)	-	-	-	25	-	-	-	-	-	-	2
	3 to 4	-	(5/)	-	-	-	-	-	-	-	-	-	-	0
Western redcedar	0 to 1	1.10	.76	1.03	30.3	13.5	-	63.0	63.2	81.5	64.5	64.8	69.4	6
	1 to 2	1.24	.97	1.22	19.2	12.2	19,701	36.7	35.4	18.5	34.8	34.7	29.7	10
	2 to 3	-	-	-	-	-	5,837	-	-	-	-	-	-	9
	3 to 4	.25	-	.25	.0	.0	1,692	.3	1.4	.0	.7	.5	.9	9

1/ Total length in all samples for unattached root sections less than 2.0 mm. in diameter. Measurements not taken for the 0- to 1-foot level.
2/ Expressed as a percent of total length in 4 feet of soil.
3/ Number of soil samples in 10 containing roots of the species.
4/ No rootlets present on root sections.
5/ No roots present in sample.

with its associate tree species. The lower rootlet and root tip mortality of white pine suggests that the above normal summer precipitation of the last 3 years apparently has been favorable to white pine.

White pine trees on healthy areas with deeper soils capable of holding 6 to 8 inches of available moisture in the upper 3 feet of soil have approximately 75 percent of their absorbing surface in the upper 2 feet of soil (5). This species on the study area had about 80 percent of its absorbing surface in the upper 2 feet of a 3-foot depth. Not only does white pine on the diseased area have to compete with species having more profuse fine root systems, but a greater share of its water demand must be supplied by lateral roots with a subnormal fine root system located at considerable distances from the tree trunk.

Though more conclusive evidence is needed, fine root development of white pine is favored and mortality is reduced under conditions where competition is restricted and available moisture is high. In zones where the reverse condition occurs, its ability to regenerate the normal components of its absorbing system is apparently low or rootlets suffer periodically from rather high mortality from which the white pine root system on the study area has not recovered.

The results of this study will have more significance when moisture usage, the ability to absorb moisture from soil per unit area of root surface, and the absorptive abilities of different root structures of each species are determined. The greater abundance of a fine root system means only a greater potential absorptive surface. The relative abundance of mycorrhizae on one species compared to another needs a great deal of study, though present knowledge suggests their most important role is in uptake and supply of mineral elements to their host. This study does suggest that if the above factors were constant and equal for all species, western white pine, because of its less profuse fine root system, would not be able to compete as efficiently for water and mineral uptake as other species within pole blight areas.

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